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EFFECT OF IMAGE UPDATE RATE ON MOVING-TARGET IDENTIFICATION RANGE

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In prior research, moving-form perception tended to be nonveridical when the update rate of an image generator (IG) was less than the refresh rate of the display device. In this experiment, we examined the effect of update rate on the range at which pilots could identify computer-generated represenations of moving aircraft. For a 60-Hz interlaced display, identification range was greater for a 60-Hz image update rate than for a 30-Hz update rate. This effect held for two views of three pairs of aircraft moving at two different velocities. These results suggest that image update rate is an important design parameter for simulators intended to support air-to-air combat training. To maximize the range at which a moving target can be identified, the update rate of the IG should equal the refresh rate of the display device.

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PREFACE

This work was performed by the University of Dayton Research Institute (UDRI) and the Armstrong Laboratory, Aircrew Training Research Division (AL/HRA) at Williams Air Force Base, AZ. Research was conducted under Work Unit 1123-03-85, Flying Training Research Support, Contract F33615-90-C-0005, and in-house Work Unit 1123-32-03, Tactical Scene Content Requirements. Contract Monitor was Ms Patricia A. Spears and the Principal Investigator was Dr Elizabeth L. Martin.

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EFFECT OF IMAGE UPDATE RATE ON MOVING-TARGET IDENTIFICATION RANGE

INTRODUCTION

It is important that the visual systems of flight simulators provide enough target (airborne or ground) information for the pilot to make appropriate tactical decisions. With current technology, however, targets are typically not identifiable at realistic ranges. In response to this problem, the engineering community is endeavoring to improve the resolution, contrast, and brightness of display devices and to increase the number and addressability of image generator (IG) channels. Less attention is being paid to the temporal characteristics of visual systems. This is unfortunate. Although high spatial resolution is necessary for the presentation of target detail, the temporal characteristics of a system can affect the perception of that detail. Of interest here is the perceptual effect of image update rate--or equivalently, in this experiment, the perceptual effect of the ratio of the display refresh rate to the image update rate.

Most raster-graphics displays are refreshed at 60 Hz. Electron beams in the display device trace a fixed pattern of horizontal lines, from left to right and from top to bottom. If the raster is noninterlaced, all of the horizontal lines are scanned during each refresh period. If the raster is interlaced, the odd- and even-numbered lines are scanned during successive refresh periods. Currently, most flight simulator displays are interlaced.

Each digital image in a simulator IG represents a view of the database scene at a particular point in time. This image is recomputed at some "update" rate, which may be less than the refresh rate of the display device. For example, an IG coupled with a 60-Hz, interlaced display device can update once every field (60 Hz) or once every frame (30 Hz). Similarly, an IG with a

noninterlaced display can update every frame (60 Hz) or every other frame (30 Hz). Some IGs update at less than 30 Hz or respond to overload problems by reducing their nominal rate. Whenever the update rate is less than the refresh rate, the last image is displayed repeatedly until computation of the next image is completed.

In computer-generated imagery, relative motion of an object is portrayed by appropriate differences over frames or fields in the size, shape, and location of the object's spatial representation. The exact sequence of images for a given object trajectory depends upon the update rate of the IG and the refresh pattern and refresh rate of the display device.

Lindholm (1992b) examined the effects of image update rate and display interlacing on the perception of a small geometric form moving horizontally at a constant virtual velocity. She found that form perception was usually veridical when the update rate of the IG equaled the 60-Hz refresh rate of the display device, regardless of whether the display was interlaced or noninterlaced. In contrast, form perception tended to be nonveridical when the update rate was less than the refresh rate. When the update rate was 30 Hz and the display was noninterlaced, the perceived form was a double image of the displayed form, with the two halves of the composite separated by half the distance between successive displayed locations. When the update rate was 30 Hz and the display was interlaced, the perceived form was a comparable composite of the partial form representations in the two fields.

In the present experiment, we examined the effects of image update rate on the range at which pilots could identify moving models of aircraft with which they were already familiar: F-15, F-16, and MiG-29. These aircraft were chosen because they could be simultaneously present in a tactical scenario.

METHOD

Subjects

Twelve fighter pilots served as observers. Their ages ranged from 28 to 46 years; their air-to-air combat training ranged from 200 to 1,015 hours. Prior to testing, each observer was informed of the general purpose of the experiment.

Apparatus and Visual Displays

The images were generated by General Electric's Advanced Visual Technology System (AVTS), a research and development system similar to the COMPU-SCENE IV. AVTS has an addressability of 985(V) x 1000(H). It supports an interlaced display device. When AVTS is set to operate at a 60-Hz update rate, the digital images for the two fields of a frame are based on different samples of the scene. When it is set to operate at a 30-Hz update rate, the images for the two fields are based on the same sample.

A Barcographics 800 CRT projector was used to display the images on a 6 x 6 ft (1.8 x 1.8 m) flat screen. The observer sat 3 ft (.9 m) from the screen with his head position maintained by a chin rest. From this viewing distance, the display image subtended a 90 x 90 degree (deg) field of view. A two-button response box was used to initiate a series of trials and to indicate aircraft identity.

Three-dimensional, all-white models of an F-15, an F-16, and a MiG-29 were created on AVTS. Representations of these models were displayed against a blue background during testing. Prior to each session, the projector was adjusted so that the luminance of the model representations (at a simulated range of 500 ft [152 m])

was approximately 6 fL and the luminance of the background was approximately .4 fL. The room was darkened during testing.

A test trial consisted of a 1-s display of a target aircraft moving horizontally. The simulated distance from the viewpoint to the aircraft was constant throughout a trial. The starting point of each flight sequence was adjusted so that the displayed trajectory was centered on the screen. The update rate (30 or 60 Hz) of the IG and the direction (left or right), speed (400 or 800 knots), view (planform or side) and range of the aircraft were varied across trials.

High-resolution representations of the planform and side views of the three aircraft models are shown in Figure 1. The actual representations during testing depended upon the update rate of the IG, the simulated range and velocity of the aircraft, and the projected position of the model on the pixel mosaic.

Because the display was interlaced, only every other line of the display raster was presented during a refresh period. If the update rate was 30 Hz, the aircraft representations in the two fields of a frame were horizontally aligned. If the update rate was 60 Hz, the aircraft representation in the second field was displaced (in the direction of motion) relative to that in the first. The simulated velocity determined the magnitude of the displacement.

The simulated range of an aircraft affected not only the size but also the shape and contrast of its representation. To reduce spatial aliasing, the digital "color" of each pixel in an AVTS image is computed by sampling and averaging the colors of 16 subpixels. To reduce the possibility that small moving features will be "lost" due to interlacing, the subpixels that determine the content of a given pixel extend beyond the spatial boundaries of

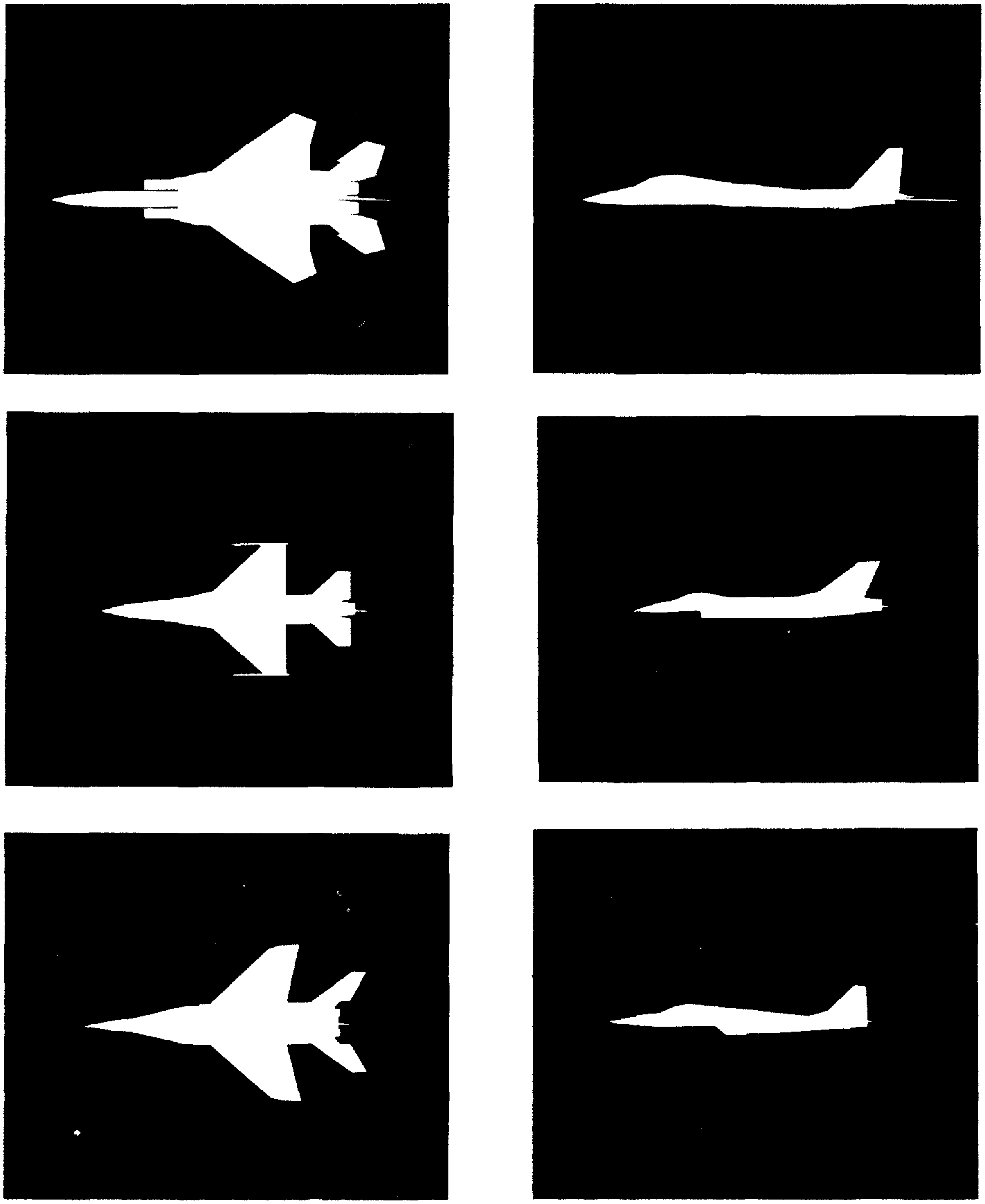

Figure 1
Illustration of the Two Views of the Three Aircraft Models. The planform (left column) and side (right column) views of the F-15, F-16, and MiG-29 are shown in the top, middle and bottom panels, respectively.

that pixel. Thus, the representations of objects that subtend only a few pixels tend to be blurred and of low contrast.

Design

Six stimulus sets were created from the two views of the three aircraft. Each set consisted of one view of two aircraft. One set was assigned to each block of trials. The observer's task for each block of trials was to indicate which of the two designated aircraft had been presented.

A transformed up-down staircase procedure (Levitt, 1971) was used to provide an estimate of the range at which the observer's identification accuracy was 79% (X_{79}). The range for the first trial of each staircase was 2,025 ft (1/3 nmi). The range on subsequent trials depended upon the response history. Every time the observer made an identification error, the range was decreased. Three correct responses resulted in an increase in range. The magnitude of the step size (change in range) was reduced during the course of a test. The initial step size was .1 log unit. The step size was reduced to .05 log unit after the first run (sequence of trials in which the changes in range were all in one direction) and to .025 log unit after the third run. A staircase was terminated after 5 runs or 60 trials, whichever occurred first.

With the 90-degree field of view, the minimum range at which a full 1-second, 800-knot motion sequence could be displayed was 891 ft (272 m). This range was set as a minimum for both speeds. Thus, if the next step in a staircase would bring the aircraft closer than 891 ft (272 m), the range was not decreased. Trials were presented at the range just greater than the minimum until the observer was correct three times in succession.

Each observer was tested with all 24 combinations of 2 update rates (30 Hz and 60 Hz), 2 aircraft views (planform and side), 3 aircraft pairs (F-15/F-16, F-16/MiG-29, F-15/MiG-29), and 2 velocities (400 knots and 800 knots). The testing was distributed across two sessions. Half of the observers were tested with the planform view on the first session and the side view on the second session. Half of the observers were tested in the reverse order. Within a session, half of the observers were tested with each of the aircraft pairs at 60 Hz and then with each of the aircraft pairs at 30 Hz. Half of the observers received the two update rates in the reverse order. Presentation order was counterbalanced across observers and sessions, such that observers who received 60 Hz followed by 30 Hz for the planform view received 30 Hz followed by 60 Hz for the side view, and vice versa. The order of pair presentation was latinized across the three subjects within a group, where a group was defined by the order in which the observers received the two update rates and aircraft views.

Within a staircase, aircraft and direction of motion were chosen randomly on each trial. Trials for the two velocities for a given update rate x aircraft pair x aircraft view combination were randomly interleaved.

Procedure

At the beginning of an observer's first session, the experimental task was described. The instructions included the information that under some conditions they were likely to see a "double image" when a moving aircraft was presented.

To ensure that the observer could identify the spatial representations of the aircraft models at a variety of ranges, each set of trials began with a sequence of static presentations. The 2 aircraft models for that set were presented side-by-side at 500, 1,000, 2,000, and 4,000 ft (152, 305, 610, and 1,219 m),

respectively. The timing of this cycle, which was repeated twice, was under the control of the observer. Each of the 2 aircraft was then presented for identification 4 times at each of the 3 closer ranges. The order of presentation of the 6 aircraft x range combinations was random within each set of 6 trials. This familiarization procedure was repeated until the observer made 2 or fewer errors during the 24 identification trials.

The test trials were initiated after the observer had met the identification criterion. Observers were given the opportunity to take a break after each block (i.e., after the 2 interleaved staircases for a given update rate x aircraft pair x aircraft view combination). A typical testing session was completed in about 45 min.

RESULTS

On 5 of the 288 (12 observers x 24 conditions) staircases, the 60-trial limitation resulted in termination of the staircase before 5 runs had been completed. Except for these cases, in which only the second and third reversals were used, estimates of X_{79} were obtained for each staircase by averaging the log range values associated with the last four reversals. The minimum range restriction was reached 1 or more times on 5 staircases.

The log X_{79} estimates were subjected to a 6-way analysis of variance with two grouping factors and four within-subjects factors. The grouping factors were "order" and "session." The former indicated the order in which the two update rates were presented for the planform view; the latter, the session on which the planform view was presented. The within subject factors were update rate, aircraft view, aircraft pair, and velocity.

Aircraft identification range was significantly greater for the 60 Hz update rate than for the 30 Hz update rate, $F(1,8) = 290.79$, $p < .0001$. Although the magnitude of the difference between update rates was greater for the side view than for the planform view, $F(1,8) = 32.34$, $p < .0005$ (Fig. 2), subsequent analyses indicated that the effect was significant for both views.

A significant view x update rate x order interaction, $F(1,8) = 10.76$, $p < .02$, provided some evidence that the magnitude of the update effect varied with within-session practice. It will be recalled that half of the observers (Order 1) received a 60/30 Hz presentation order for the planform view and a 30/60 Hz presentation order for the side view. The other half (Order 2) received the reverse ordering. For Order 1, then, a practice effect would have reduced the update rate effect for the planform view and increased the update rate effect for the side view, whereas for Order 2 a practice effect would have had the opposite result. Therefore, if practice with a given view of the aircraft increased the range at which they could be identified, the interaction of aircraft view and update rate should have been larger for Order 1 than for Order 2. As shown in Figure 3, such was indeed the case. Further support for this interpretation was provided by subsequent analyses in which the data for the two aircraft views were analyzed separately and observers were grouped according to the order in which they received the update rates for the view under consideration: For both views, the effect of update rate was greater for those observers who were tested with the 30-Hz update rate first.

The update rate x velocity interaction was also significant, $F(1,8) = 5.76$, $p < .05$. Whereas there was no effect of velocity for the 60-Hz update rate, identification range was greater for a velocity of 400 knots than for a velocity of 800 knots when the

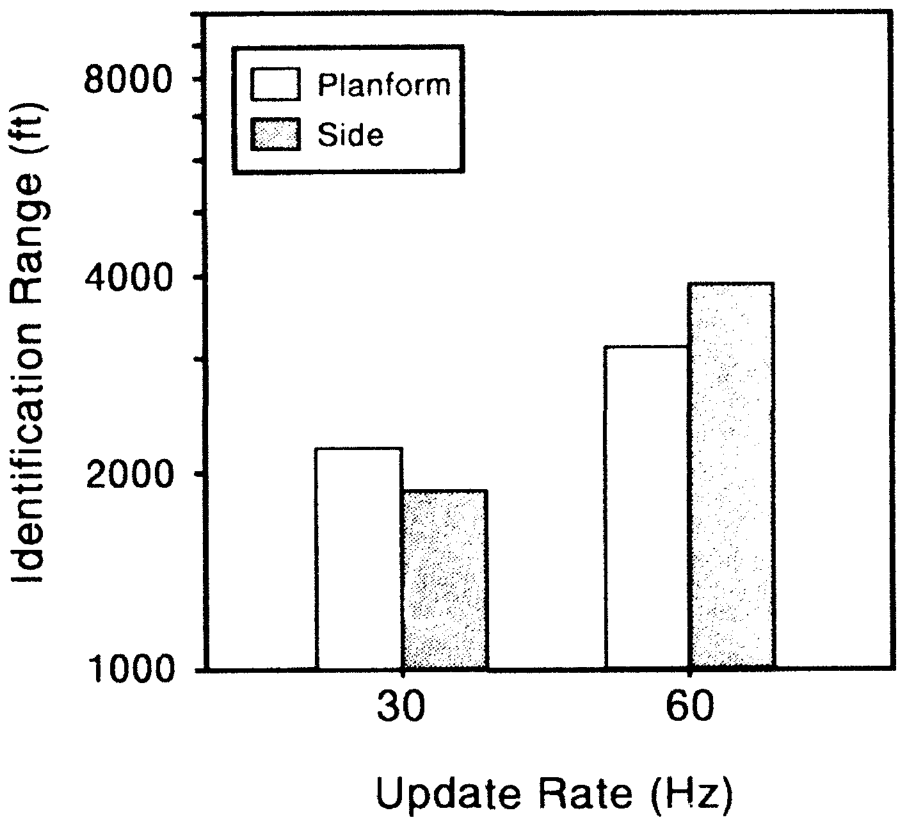

Figure 2
Identification Range as a Function of Update Rate
and Aircraft View

update rate was 30 Hz. The three-way interaction of update rate, velocity, and aircraft view did not reach statistical significance, $F(1,8) = 4.48$, $p < .10$. Nonetheless, as shown in Figure 4, the update rate x velocity interaction was limited to performance for the side-view presentations.

The main effect of aircraft pair, $F(2,16) = 15.58$, $p < .0002$, as well as the view x pair, $F(2,16) = 5.57$, $p < .02$, and view x pair x velocity, $F(2,16) = 6.25$, $p < .01$, interactions were all significant (see Figure 5). Although none of these effects varied

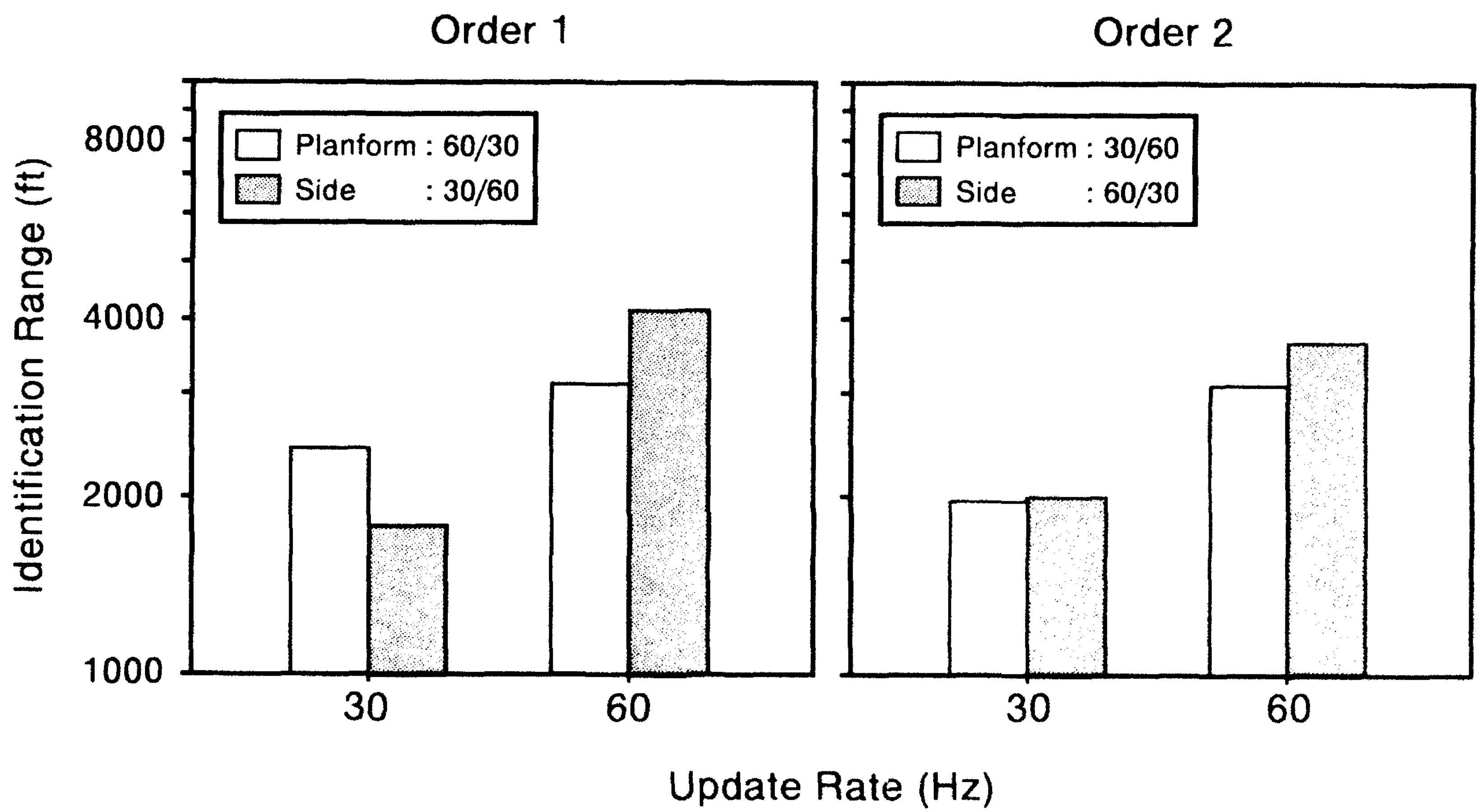

Figure 3
Identification Range as a Function of Update Rate and Aircraft View for Each Order

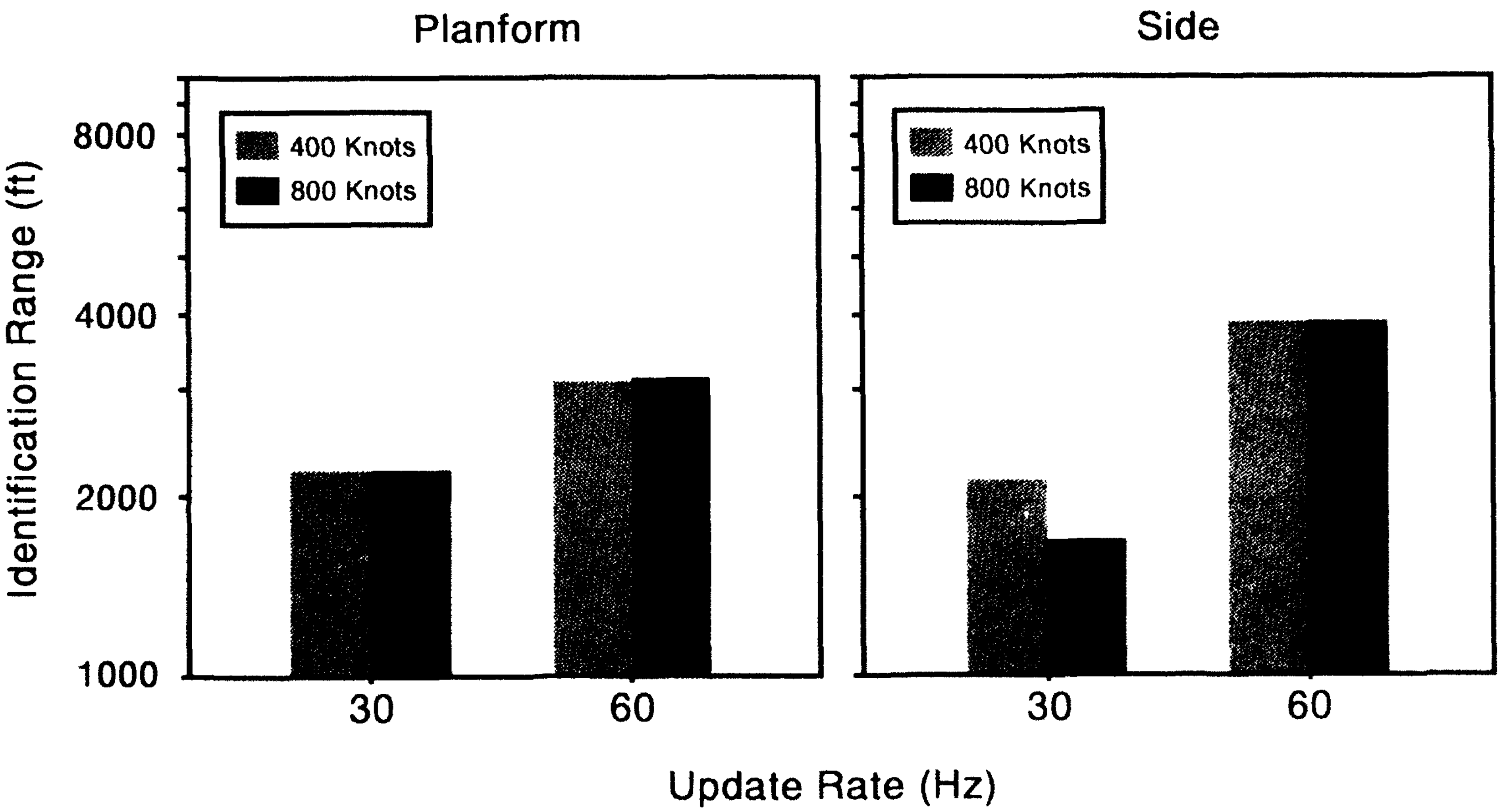

Figure 4
Identification Range as a Function of Update Rate
and Velocity for Each Aircraft View

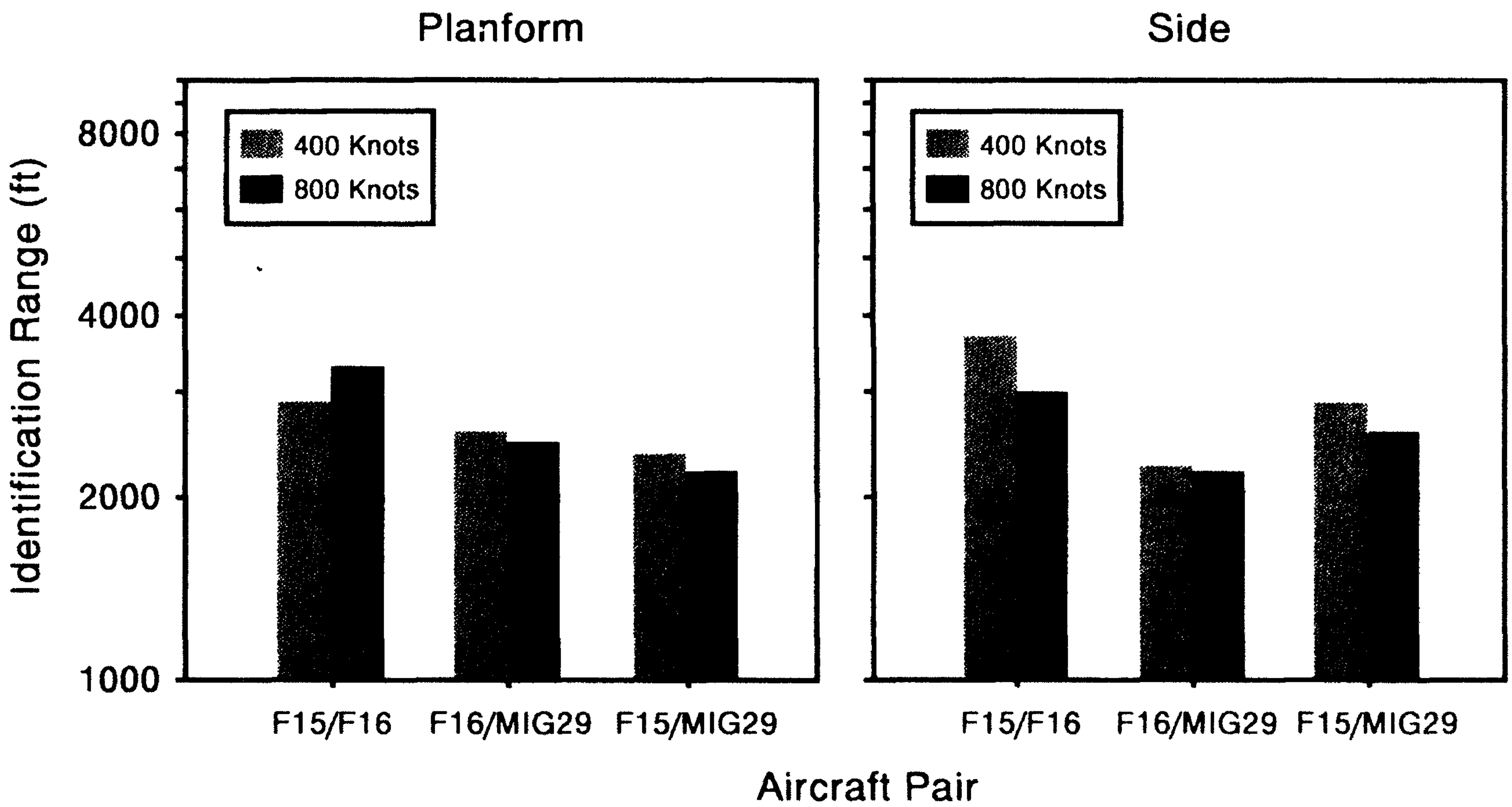

Figure 5
Identification Range as a Function of Aircraft
Pair and Velocity for Each Aircraft View

significantly with update rate, examination of the cell means for the update rate x view x pair x velocity interaction revealed that the only sizable effect of velocity was for the 30-Hz side-view presentations of the F-15/F-16 pair. (In this case, the 400-knot identification range was greater than the 800-knot identification range by a factor of 1.68. In the remaining 11 cases, this factor fell between .88 and 1.16.) This pair showed both the smallest update rate for the low speed and the largest update rate effect for the high speed. Thus, the velocity effect for the 30-Hz presentations was not attributable to an aberrant effect of update rate for just one of the two velocities.

The only other statistically significant effect was the interaction of velocity and session, $F(1,8) = 5.97$, $p < .05$. Given that the session variable merely coded the order in which the two views were presented, and that there was no evidence of either a view x session or a view x velocity x session interaction, it is unlikely that this effect would replicate.

DISCUSSION

The results of this experiment support and extend previous investigations of the effects of update rate on the perception of computer-generated images of moving objects. For a 60-Hz interlaced display, we found that aircraft identification range was greater when the update rate was 60 Hz than when the update rate was 30 Hz. This effect was very robust, holding over two views of three pairs of aircraft moving at two different velocities.

The magnitude of the update rate effect did, however, vary with aircraft view. Although performance was better for the side view than for the planform view when the update rate was 60 Hz, it was better for the planform view than for the side view when the update rate was 30 Hz. The form of this interaction suggests that

the 30 Hz update rate resulted in greater degradation of the features important for identification of the aircraft from the side than of the features important for identification of the aircraft from the top. If reducing the update rate had merely made identification more difficult, the magnitude of the update rate effect would have been either equal for the two views or larger for the more difficult.

Although we did not do a formal analysis of the features available to or used by our observers, the three aircraft differed appreciably in size (see Fig. 1). The apparent size of the target was thus a potential cue to target identity. It is unclear, however, to what extent our imagery supported veridical size perception. Because of the variation in range, the size of an aircraft representation was not a reliable indicator of the size of the aircraft. Recall that successive trials could be from the same staircase or from different staircases. If they were from the same staircase, the range on successive trials would either not change or change by the step size for that staircase. In contrast, if they were from different staircases, the change in range from trial $\underline{n}$ to trial $\underline{n} + 1$, which would be determined by the differences between the two response histories, could be quite large. Moreover, while the apparent size of a given representation would be expected to vary with apparent range, the only independent cue for range was the length of the motion path. This cue was not completely reliable because of the variation in velocity. (For example, the trajectory of an aircraft traveling at 400 knots at a range $\underline{r}$ equals that of an aircraft traveling at 800 knots at a range $\underline{2r}$.)

Nonetheless, several findings suggest that apparent size may have been an important cue to target identity. First, for both aircraft views, the pair of aircraft that differed most in size (i.e., the F-15 and the F-16) resulted in the best performance. Second, the difference in the magnitude of the update rate effect

for the two aircraft views can be accounted for by differential effects of the slower update rate on the size cues in the two views. With a 30-Hz update rate, the components of the double image are offset in the direction of motion. Thus, whereas a 30-Hz update rate would have increased the horizontal extent of the percept that resulted from a particular aircraft representation, it would not have affected the vertical extent. When the aircraft were viewed from the top, their representations differed in both horizontal and vertical extent; when viewed from the side, size variation was more-or-less limited to the horizontal dimension (see Fig. 1). Thus, the slower update rate would have caused more distortion of the size information in the side representations than of the size information in the planform representations.

Because the perceived displacement of the two components of a double image increases with target velocity, a 30-Hz update rate may also have resulted in velocity-specific losses or distortions of important features in the spatial percept. The velocity effect for the 30-Hz, side-view presentations of the F-15/F-16 pair may be attributable to such velocity-specific effects.

Regardless of the particular perceptual distortions responsible for the observed update-rate effect, the data indicate that moving models will tend to be identifiable at a greater range on a system with a 60-Hz update rate than on a system with a 30-Hz update rate. Although this basic finding should hold for a variety of objects and velocities, the magnitude of the effect probably cannot be estimated from the present results. The obtained identification ranges were dependent not only upon the specific aircraft views and velocities but also upon the spatial resolution of the system and the exact nature of the task.

Identification accuracy always varies with the size of the stimulus set and the similarity of the alternatives. With the procedure used here, only two alternatives were presented during

any one set of trials. In addition, the estimates obtained by the staircase procedure may have been somewhat biased. This method provides only unbiased estimates when the expected proportion of a correct response is a monotonic function of the stimulus level (range, in this case). At the minimum range in this experiment, however, an aircraft moving at 800 knots would have traversed the 90-degree field of view in 1 second. It is, therefore, unlikely that the observers were able to track the target at all range and velocity combinations. Failure to track the target would presumably have eliminated the double images associated with a 30-Hz update rate. Instead, for both update rates, the target may have appeared to be simultaneously present in several of its (overlapping) displayed locations (Lindholm, 1992a). Thus, when a decrease in range reduced the observer's ability to track the target, it may well <u>not</u> have increased the probability of a correct identification response. In addition, whenever the minimum range was reached, the staircase procedure was disrupted, and the minimum range was taken as an estimate of the identification range. Truncation of testing when a 60-trial limit was reached may also have introduced bias. Finally, the estimates for a given observer were often highly variable. This variability suggests a change in discrimination criteria over time. (Informal comments by some of the pilots substantiate this view.) Nonetheless, the data were quite orderly and the estimates for the two velocities were comparable for most conditions.

Finally, it should be emphasized that the superiority of a 60-Hz update rate presupposes a 60-Hz display device (the current industry standard). According to the analysis of Lindholm (1992b), nonveridical form perception will occur when the update rate of the IG is less than the refresh rate of the display device. Thus, if a 120-Hz display were used, a 120-Hz update rate would be necessary. Furthermore, one should consider that research accomplished to date has been limited to the study of the effects of update rate on form perception. Additional research is needed

to determine whether update rate has an equally profound impact on the perception of other types of dynamic scenes, such as low-altitude flight imagery. Researchers at AL/HRA are currently investigating the effects of update rate on the apparent velocity of textured terrain.

In conclusion, the results of this research have important implications for the design of flight simulators intended to support tactical air-combat training. Traditional engineering approaches have emphasized the spatial resolution of the system. This study indicates that the temporal characteristics of the system are also important. Most high performance IGs can operate at 60 Hz, usually by reducing scene content. Low cost IGs typically update the image at 15 Hz or 30 Hz. Assuming a standard interlaced or noninterlaced 60-Hz display, we recommend a 60-Hz update rate for any simulator intended to support air-to-air combat training. If the update rate of the display is increased, the update rate of the IG should be increased accordingly.

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